Disregarding the months of lesser weight, indicated by the small number of days, it appears that these two widely separated stations agree in showing that the solar constant was decidedly higher in 1914 than in 1913.

Finally, the 29 days with solar-constant values available for favorable comparison between Arequipa and Mount Wilson have been grouped into high values and low values, as indicated by Mount Wilson work and the resulting mean solar constants (with their differences) are shown in Table 4.

TABLE 4.

Station.	Group A.	Number days.	Group B.	Number days.	A–B.
	Gr.-cal.		*Gr.-cal.*		*Gr.-cal.*
Mount Wilson	1.954	15	1.893	14	0.061
Arequipa, formula (3)	1.936	15	1.900	14	.036
Arequipa, formula (4)	1.943	13	1.907	14	.036

This tends to confirm the previously discovered short-period irregular solar variations.

The author sums up his results as follows:

Observations with the silver-disk pyrheliometer and nearly simultaneous measurements of atmospheric humidity have been made since August, 1912, at Arequipa, Peru, at the station of the Harvard College Observatory.

From these observations have been determined values of the solar radiation at Arequipa corresponding to sec. z=1.0, 1.2, and 2.0; values of pressure of aqueous vapor, and values of the diminution of radiation attending the passage of the sun from the zenith distance whose secant is 1.0 to that whose secant is 2.0.

Owing to other occupations the observers have generally made these observations when the sun was within 60° of the zenith. On this account determinations of atmospheric transparency are not always possible, and are of less weight than other data given.

The results are collected to give monthly mean values. These show a remarkably close connection between radiation and vapor pressure. Advantage is taken of this close correlation to determine by empirical formulæ values of the solar constant of radiation. These empirical values agree quite as well as could be expected with values obtained at Mount Wilson, Cal., by complete spectrobolometric and pyrheliometric measurements combined. The Arequipa results confirm the variability of the sun, both from year to year and from day to day, shown by investigations at Mount Wilson and elsewhere.

It seems probable that from observations similar to those at Arequipa, if conducted at 8 or 10 favorable stations of high level in various parts of the world, the variations of the sun could be determined almost or quite as certainly as from two stations equipped for complete spectrobolometric determinations of the solar constant.

The Arequipa results indicate that the volcanic dust which was general in the atmosphere in the Northern Hemisphere for more than a year after the volcanic eruption of Mount Katmai, Alaska, in June, 1912, did not influence the transparency of the atmosphere in Peru.

551.59...(77..)

HORIZONTAL RAINBOWS ON LAKE MENDOTA.

By CHANCEY JUDAY.

[Laboratory of the Wisconsin Geological and Natural History Survey, Madison, Wis. Feb. 26, 1916.]

During the past decade horizontal rainbows or color spectra have been observed a number of times on the surface of Lake Mendota at Madison, Wis. These spectral phenomena have not appeared every year during this period of time, but they have been noted during at least 5 of the past 10 years and on more than one date in each of the 5 years. With one exception, namely, May 24, 1915, they have been confined to the autumn of the year. They have varied in extent from mere bright spots, in which the spectral colors were scarcely discernible, to brilliant bows which have attracted considerable attention.

Previous observations.

Such phenomena have been observed on various bodies of water in Europe, and the fact that they appear most frequently in autumn has led the Swiss and German writers to designate them as "Herbstiris." Apparently the first record of such a phenomenon is that cited by Forel,[1] who states that Wartmann observed two displays of iris on the surface of Lake Geneva, Switzerland. One was noted on November 2, 1868, and the other on February 11, 1872. Similar phenomena were noted on Lake Geneva by two other observers, one on July 5, 1871, and the other on December 28, 1876. Wartmann attributed the spectra which he saw to the existence at the surface of the water of a considerable quantity of powdery material. These small particles produced a series of depressions in the surface film which acted like a prism in dispersing the rays of light. Forel himself expresses the opinion that these spectra were produced by thin layers of oil on the surface of the water.

J. C. Maxwell[2] described a horizontal rainbow that was seen at about noon on January 26, 1870, on the frozen surface of the ditch surrounding St. John's College at Cambridge, England. He attributed the spectral display to drops of water on the surface of the ice. The angle between the bright red of the bow and the sun's ray was 41° 50′ while that of the blue was 40° 30′.

Hewitt[3] states that a horizontal rainbow was seen on Lake Windermere, England, by Kay in November, 1885. On November 6, 1903, Hewitt observed two spectra, one of which was fainter than the other, on one of the ponds in Vernon Park at Stockport, England. These rainbow colors were visible for more than four hours and were produced by droplets of water which a fog deposited upon a film of carbonaceous dust resting upon the surface of the pond.

Hann[4] observed a rainbow on Lake Constance on September 25, 1903, during a foggy morning. In describing the phenomenon he states that "es waren die Fusspunkte eines Regenbogens, der aber nur in dem Nebeldunste über dem See seinen Ursprung haben konnte."

On April 11, 1906, Church[5] saw a horizontal bow on Loch Lomond, Scotland. It was a perfectly still, cloudless day, and the phenomenon was attributed to a film of fog left undisturbed on the calm surface of the water.

Schaffers[6] has described a horizontal rainbow which he saw on a small pond in the vicinity of Louvain, Belgium. He attributed it to droplets of water about a tenth of a millimeter in diameter which rested upon a scum composed of minute animals and plants. This bow had the form of an arc of an ellipse. The angular distance of the primary bow was 40° to 42° and, rarely, a secondary bow appeared at an angle of 53°.

Schroeter[7] has described a rainbow which he saw on the surface of Lake Zurich. According to him it was produced by droplets of water deposited by mist or fog upon an oily scum that covered the surface of the lake. Wyss[8] has also observed this phenomenon on Lake Zurich a number of times, and he has attributed it to the presence at the surface of the lake of very large numbers of the small crustacean *Daphnia longispina*. These daphnids come to the surface in great numbers in the

[1] Le Léman. II, p. 505, 1895.
[2] Proc. Roy. Soc. Edinb., 1869–72, 7:69; Sci. papers, v. 2, p. 160.
[3] Nature (London), 1903, 69:57.
[4] Meteorolog. Ztschr., Wien, 1903, 20:520.
[5] Nature (London), 1906, 73:608.
[6] Nature (London), 1906, 74:125.
[7] Internat. Rev. d. ges. Hydrob. & Hydrog., 1908, 1:747.
[8] Revue Suisse de Zoöl., 1909, 17:441.

autumn, and the ephippia which they bear possess cross-hatch markings which, according to Wyss, act as diffraction gratings in separating the sunlight into its primary colors.

Wesenberg-Lund [9] records having seen such a display on a pond after it was covered with ice. He states that it was produced by droplets of water resting on an oily scum covering the surface of the ice.

Japanese [10] observers have seen these horizontal spectra on the moat surrounding the Central Meteorological Observatory and on Sinobazu pond at Tokyo and on the surface of Lake Suwa. One of them, Fujiwhara, has attributed this phenomenon to droplets of water floating in the air over the surface of the lake or pond but not resting upon the surface of the water or the ice.

Observations on Lake Mendota.

With respect to their origin, it may be said that the horizontal bows observed on Lake Mendota were produced by small drops of water resting upon a scum which covered the surface of the lake, thus preventing the coalescence of the drops with the water beneath. When the sunlight strikes these droplets, the beams of light are reflected and refracted just as they are in the raindrops which produce the regular rainbow. Measurements show that the angular distances in the horizontal bow are substantially the same as those of the regular rainbow, thus indicating that the horizontal bows are produced by drops of water and not by something which serves as a diffraction grating. The droplets borne by the scum may also be readily recognized with a hand lens.

The type of horizontal bow most frequently seen on Lake Mendota consists of one or two more or less brilliant spots of light in which the spectral colors are readily distinguishable. These spots represent the segments of the bow. If conditions are more favorable, the bow is complete but parabolic in form instead of semicircular, as in the regular rainbow, with the observer at the apex of the parabola. (See fig. 1.) The outer extremities of the bow constitute the widest and most brilliant parts, and from them two narrow, bright bands of light approach the observer. Usually the spectral colors are scarcely recognizable in these bands, but sometimes yellow and red are readily discernible. Sometimes the primary bow is double, the inner bow only rarely being complete. The secondary bow appears at some distance outside the primary bow, with the colors in the reverse order, just as in the regular secondary rainbow. Usually it is nothing more than a bright spot of light, but sometimes it is brilliant enough to show the spectral colors distinctly. No band between the observer and the bright spot of the secondary bow has ever been noted.

In general these horizontal rainbows are confined to the early hours of the day but in a very few instances they have been visible as late as 2 p. m. They have been seen when the observer was 10 to 12 meters above the surface of the lake, but no greater height than this has been tested so that the maximum altitude at which they are visible is not known. They have also been seen when the observer's eyes were within half a meter of the surface of the water; sometimes, in fact, they are brighter when the eyes are near the surface.

During the month of October, 1914, horizontal bows were observed on Lake Mendota several times, and on two dates, namely, October 6 and 23, the displays were unusually brilliant and complete. Observations were made near the middle of the lake on these days and they were made from a launch so that the eyes of the observer were approximately a meter and three-quarters above the surface of the water. As shown in the diagram (fig. 1), these horizontal bows consisted of three primary ones, Nos. 1 to 3 in figure 1, in which the colors were arranged as in the primary rainbow, that is, with the red on the outside and the violet on the inside. A secondary bow, No. 4 in figure 1, appeared at some distance outside the primaries and in it the colors were reversed.

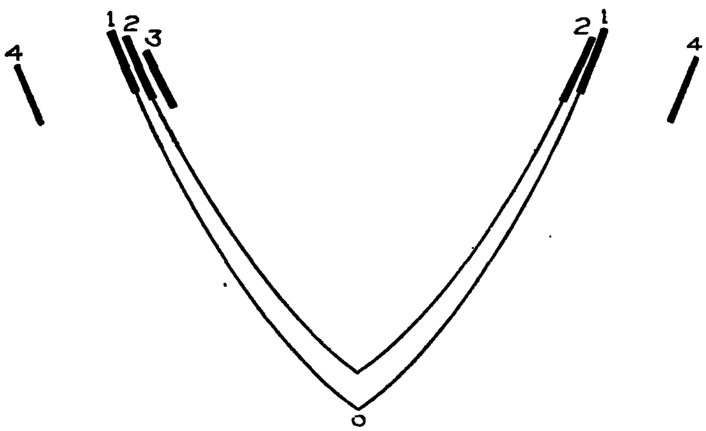

FIGURE 1.—Diagram of horizontal rainbow observed on Lake Mendota, Wis., October 23, 1914.
1, 2, 3, indicate the three primary bows.
4, the secondary bow.
O, the observer at the apex of bow 1.
The heavy lines at the outer ends of the bows indicate the widest portions in which the spectral colors, red outside and violet inside, were distinct. These bright portions were in immediate mutual contact, but have been separated in the diagram for the sake of clearness. They are represented as about 250 meters from O.

The outside member of the primary series, No. 1, was the main bow and was complete on both dates. That is, from the bright portion at the extremities where the spectral colors were very distinct (indicated by a wider line in the diagram) a bright band extended to the observer on either side as shown in figure 1. Just inside this was bow No. 2 which was complete on October 23 as shown in the diagram, but which lacked the bright bands approaching the observer on October 6. The red at the extremities of bow No. 2 was in immediate contact with the violet of bow No. 1, but they have been separated in the diagram in order to show the two more distinctly. The bright bands approaching the observer were distinctly separated from those of No. 1 and they met about 20 meters in front of the observer. Bow No. 3 was distinctly seen on both of the above dates but it was limited to the left segment, no trace of it being visible on the right side. It did not contain all of the primary colors, only red, orange and yellow being visible. Neither did it possess a band approaching the observer. In this instance also, the red of No. 3 was in immediate contact with the violet of No. 2, so that the three primary bows constituted a continuous series at their extremities.

The distance of the chief, or the brightest, portions of these bows from the observer seemed to show considerable variation. At times that of No. 1 did not appear to be more than 200 meters away, then again it would seem to be fully five or six times as far. The bright portion of bow No. 3 came about 30 to 50 meters nearer the observer than No. 1, while No. 2 was intermediate. The width of the bright extremity of bow No. 1 showed some

[9] Internat. Rev. d. ges. Hydrob. & Hydrog., biol. Sup., Erste Serie, 1910, p. 43.
[10] MONTHLY WEATHER REVIEW, 1914, 42:426.

variation, but in general it was estimated at 10 to 12 meters. Bow No. 2 was only one-half to two-thirds as wide and bow No. 3 only about one-third as wide as No. 1. The secondary bow, No. 4, had about the same width as No. 1.

In bow No. 1 the beams of sunlight entered the droplets of water directly and underwent reflection and refraction as in the regular rainbow, but the manner in which bows No. 2 and No. 3 were produced is not so clear. A difference in the size of the drops affects the angular distance of the bow, but it scarcely seems credible that this factor was responsible for these supernumerary bows. It seems more probable that the beams of light which produced them, first impinged upon the surface of the lake and were then reflected into the droplets.

The horizontal rainbow which was seen on May 24, 1915, possessed some features which deserve attention. As already stated it is the only one that has been observed in any other season of the year than autumn. It was visible from 6:45 a. m. to 8:30 a. m., and consisted of a single series of spectral colors. The right segment only was noted and it was complete during a considerable portion of this time. During the remainder of the time only the bright distal portion of the segment was visible.

The bright portion at the outer extremity of the bow increased in width as the sun rose higher above the horizon. At 7:20 a. m. it did not appear to be more than 5 meters wide; at 7:45 it was at least 10 meters wide, and by 8:10 a. m. its width was estimated at 30 meters; a launch resting in the rainbow and at right angles to it served as a good unit of measurement in making the last estimate. Blue and violet constituted nearly half of the bow when it reached its maximum width.

Also as the sun rose higher, the bright portion of this horizontal rainbow approached the observer, and just before its disappearance, about 8:30 a. m., the intervening distance was only 115 meters.

In conclusion it may be said that the conditions which appear to be necessary for the production of this phenomenon on Lake Mendota are as follows: (*a*) A scum or film on the surface of the water which may consist of an oily soot or of plankton organisms, generally algæ; (*b*) a fog which deposits minute drops of water on this scum; (*c*) a perfect calm which facilitates the formation of the scum and also permits the globules of moisture to remain as individual droplets; (*d*) a bright sun.

HALOS AT FORT WORTH, TEX., AND THEIR RELATION TO THE SUBSEQUENT OCCURRENCE OF PRECIPITATION.

By HOWARD H MARTIN, Assistant Observer.

[Dated, Weather Bureau, Fort Worth, Tex., Feb. 23, 1916.]

The halos recorded in the following tables were observed at Fort Worth, Tex. (lat. 32° 43′ N.; long. 97° 15′ W.). The record of halos has constituted a portion of the daily routine of a regular Weather Bureau station, established September 1, 1898. However, early unfamiliarity with the practical methods of halo observation brought about the record of many halos prior to 1910 with insufficient details as to attending phenomena. In practically all cases the actual hour of occurrence, the duration and the angular measurements were omitted. For this reason, and that these results may be compared with those obtained at York, N. Y., only those halos noted between January 1, 1910, and December 31, 1915, are used. It is believed that since January 1, 1910, not more than 5 per cent of all solar halo phenomena have escaped record.

TABLE 1.—*The number of solar and lunar halos observed at Fort Worth, Tex., Jan. 1, 1910, to Dec. 31, 1915, inclusive.*

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1910	7	1	2	5	5	2	0	3	0	1	5	3	34
1911	4	2	5	3	4	2	2	0	0	0	3	2	27
1912	6	3	3	5	5	3	2	0	0	4	1	1	33
1913	3	2	5	1	2	2	6	1	0	5	1	1	29
1914	2	3	0	1	1	4	5	0	0	4	2	1	23
1915	2	6	2	2	1	1	0	1	2	0	2	5	24
Total	24	17	17	17	18	14	15	5	2	14	14	13	* 170
Means	4.0	3.0	3.0	3.0	3.0	2.3	2.5	0.9	0.3	2.3	2.3	2.1	28.2
Smoothed means [1]	3.3	3.2	3.0	3.0	2.8	2.5	2.0	1.2	1.0	1.7	2.2	2.5	28.2

* Of this total, two are discarded in other results because of incomplete data.

[1] E. g., January $= \frac{\text{Dec.} + 2\,\text{Jan.} + \text{Feb.}}{4}$

Table 1 includes both solar and lunar halos noted during this period, showing their relative monthly frequency without regard to the time of occurrence. It will be readily seen that this section of the country observes far fewer halos than either Blue Hill Observatory, Mass., or York, N. Y. The possible reason for this may be the fact that as Fort Worth is far south of the usual cyclone "lanes," it is favored with the cirro-stratus advance guard from only those lows of the Alberta type that recurve far enough south to affect the weather at this station at all, and from the relatively infrequent southern Pacific type, moving eastward from the arid regions.

Table 2 shows the frequency with which these halos were followed by precipitation, and the average length of time before such precipitation occurred. The results show even less uniformity, with regard to the seasonal effects than do either the York, N. Y., observations or those obtained at Blue Hill. The normal length of time elapsing before precipitation (24.1 hours) is much in excess of that at York, N. Y. (20.5 hours), and of that at Blue Hill (15.6 hours). Halos at Fort Worth are by far most frequent in January, and least frequent in September. In fact, during the entire record of 18 years, but two halos, one solar and one lunar, have been recorded in the latter month.

TABLE 2.—*Relations of occurrence of halos to the occurrence of precipitation at Fort Worth, Tex., from Jan. 1, 1910, to Dec. 31, 1915, inclusive.*

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
Total number considered	23	17	17	17	18	14	15	5	2	14	13	13	168
Per cent followed by rainfall within 18 hours	17	36	28	23	28	20	23	20	50	50	22	23	26
Per cent followed by rainfall within 24 hours	22	53	33	30	40	27	30	40	50	60	36	46	36
Per cent followed by rainfall within 36 hours	39	70	44	30	61	33	30	40	50	70	66	56	48
Per cent followed by rainfall within 48 hours	55	88	50	70	72	33	48	60	50	70	66	56	59
Per cent not followed by rain in 60 hours	33	12	50	30	28	64	48	20	50	20	34	44	32
Average duration	1.8	1.7	1.8	1.9	2.0	1.9	1.8	1.7	1.8	1.8	1.9	2.0	1.8
Average hour of occurrence (first seen)	15.2	17.3	14.8	14.6	15.5	12.5	13.6	11.0	17.0	12.6	12.7	13.8	14.2
Average number of hours between halo and precipitation	25.5	23.2	22.4	28.7	22.2	25.1	26.8	31.8	27.0	17.3	21.4	17.7	24.1